U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: CALICO HILLS RISK/BENEFIT ANALYSIS - MULTIATTRIBUTE UTILITY ANALYSIS

PRESENTER: DR. JOHN LATHROP

PRESENTER'S TITLE AND ORGANIZATION: DIRECTOR
STRATEGIC INSIGHTS

PRESENTER'S TELEPHONE NUMBER: (415) 941-4950

DENVER, COLORADO
MARCH 6-7, 1991

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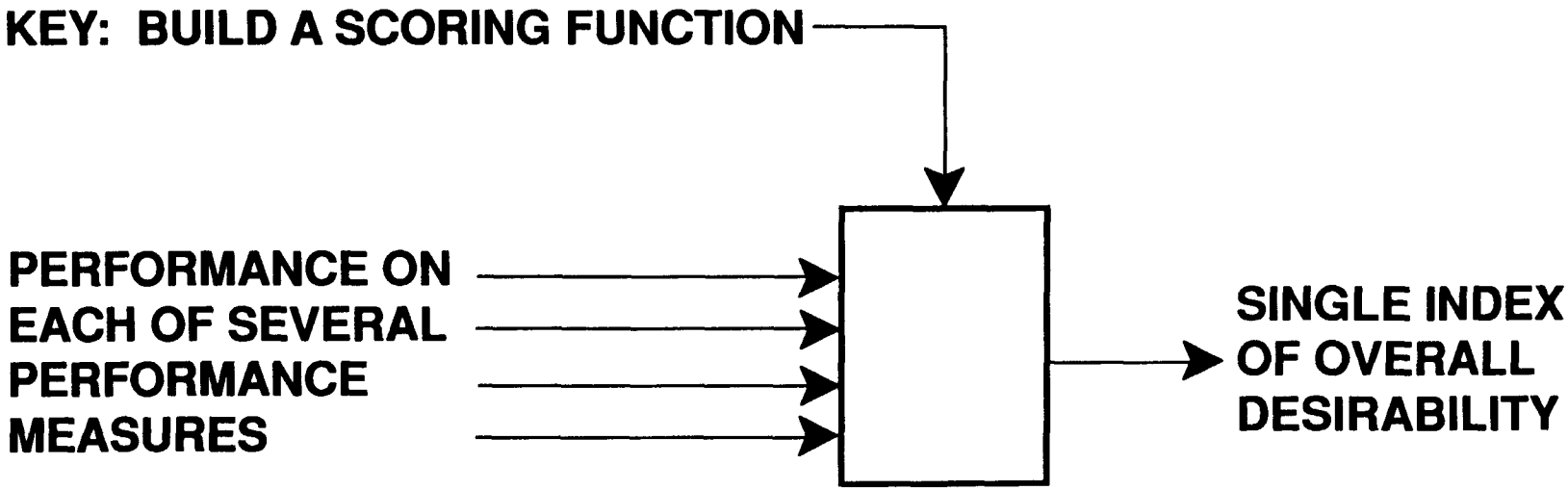
WHAT IS MULTIATTRIBUTE UTILITY ANALYSIS ?

IT IS A METHODOLOGY TO EVALUATE ALTERNATIVE ACTIONS BY HOW WELL EACH ACTION SATISFIES EACH OF SEVERAL OBJECTIVES, AS INDICATED BY SEVERAL PERFORMANCE MEASURES

KEY: BUILD A SCORING FUNCTION



SEVEN STEPS TO A MULTIATTRIBUTE UTILITY ANALYSIS

1. DEFINE OBJECTIVES, PERFORMANCE MEASURES
2. IDENTIFY PEOPLE WHOSE OPINIONS ARE TO BE INCORPORATED INTO THE EVALUATION
3. ASK VALUE ELICITATION QUESTIONS
4. FIT A SCORING FUNCTION TO THE ANSWERS
5. APPLY SCORING FUNCTION TO DATA SET
6. CONDUCT SENSITIVITY ANALYSES
7. INTERPRET RESULTS

KEY FEATURES OF MULTIATTRIBUTE UTILITY ANALYSIS (MUA)

- CAN USE SUBJECTIVE PERFORMANCE MEASURES
- CAN USE SUBJECTIVE EVALUATION ALONG EACH MEASURE
- CAN USE SUBJECTIVE EVALUATION TRADEOFFS BETWEEN MEASURES
- STRUCTURES EXPERT JUDGMENT, INCLUDING SUBJECTIVE EXPERT JUDGMENT, INTO A FORMALLY CORRECT, DEFENSIBLE ANALYSIS

WHY USE MUA HERE?

- TEST STRATEGIES VARY ON SEVERAL DIFFERENT PERFORMANCE MEASURES
- EVALUATION ALONG EACH OF THE MEASURES INVOLVES EXPERT SUBJECTIVE JUDGMENT
- EVALUATION TRADEOFFS AMONG THE MEASURES INVOLVES EXPERT SUBJECTIVE JUDGMENT

MUA VERSUS VOI

The two analyses measure different aspects of the strategies:

VOI evaluates test strategies in terms of:

how test data would affect performance (release risk, costs)

by affecting management / design decisions,

i.e., how test data would help the DOE make better decisions.

MUA evaluates test strategies in terms of:

several performance measures

(release risk, cost, scientific confidence, delay, phasing potential),

in a way not tied to how the data affects specific decisions.

Two Different Paradigms of Learning

VOI:

Analyze test accuracy and decision outcomes to derive best decision for each test outcome.

Go to rock, conduct tests.

Decide action based on test data.

Value with test minus value without test = test value.

Information has value to extent that it results in better decisions.

Each strategy has value to extent that it results in better decisions.

MUA:

Go to rock, collect data.

Learn from data in ways that cannot be anticipated.

Information has value to extent that it improves site characterization (i.e., understanding, confidence)

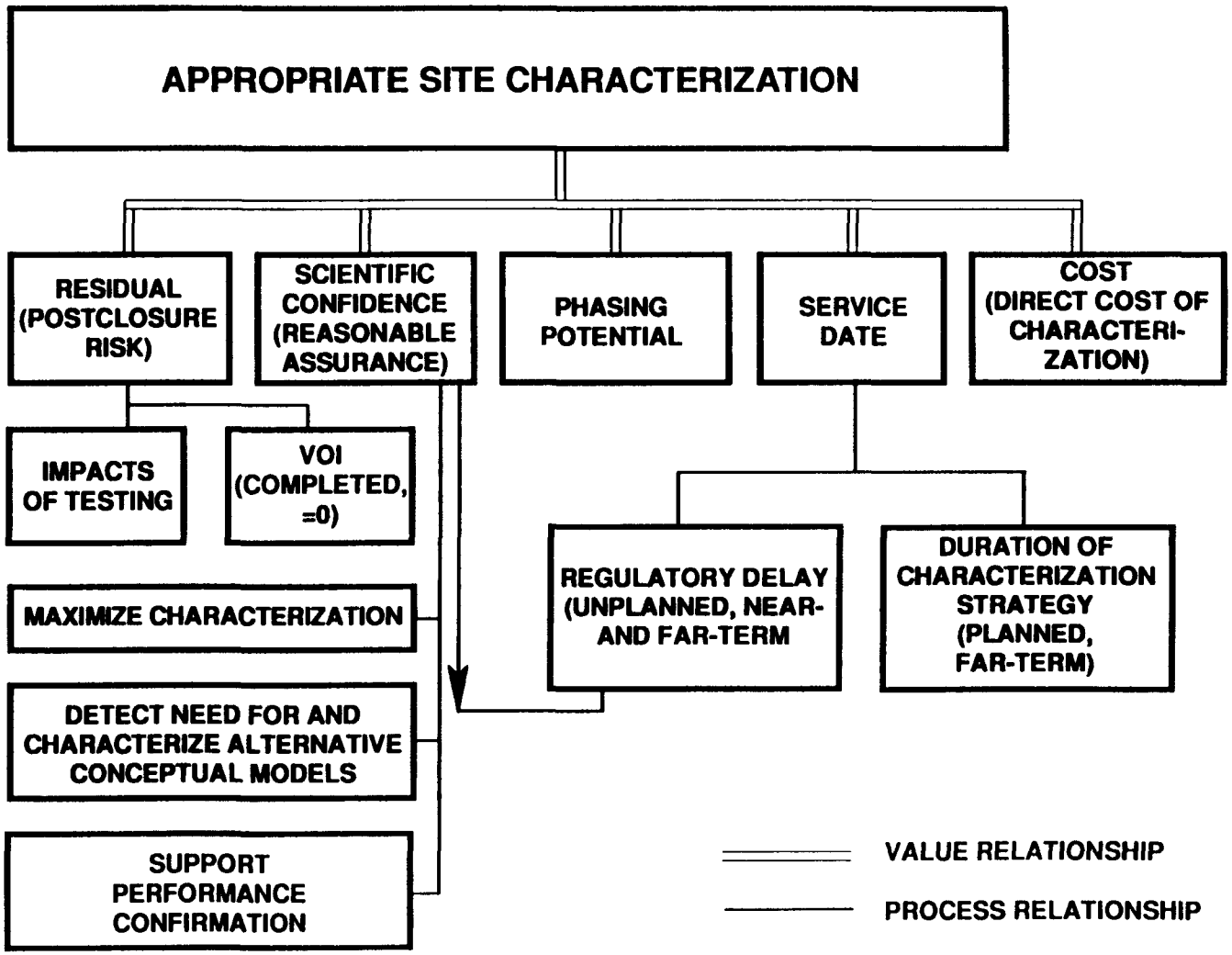
Each strategy has value simply because it exposes rock, provides opportunity to learn.

MUA VERSUS VOI

(CONTINUED)

- THE VOI ANALYSIS FOUND NO VOI IN ANY STRATEGY (SINCE NO DATA WOULD AFFECT ANY DECISION)
- THE MUA FOUND DIFFERENCES IN NET BENEFIT AMONG THE STRATEGIES
- THESE FINDINGS ARE <u>NOT</u> IN CONFLICT

ISSUES/OBJECTIVES/MODEL HIERARCHY



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ELEMENTS OF A MULTIATTRIBUTE UTILITY FUNCTION

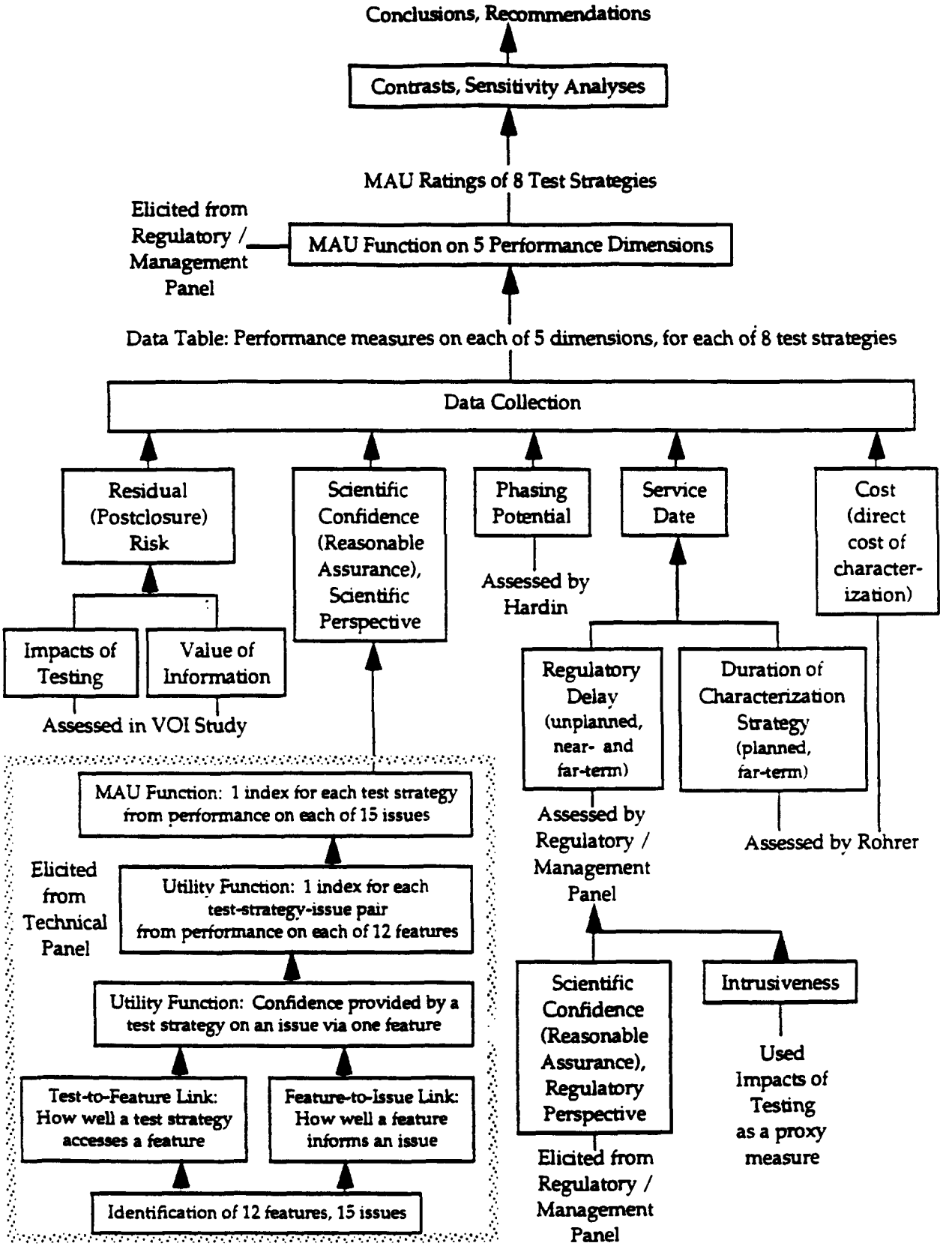
$$U(\text{ALTERNATIVE}) = k_1 u_1(x_1) + k_2 u_2(x_2) + k_3 u_3(x_3) + \text{etc. +, PERHAPS, INTERACTION TERMS}$$

x_i = PERFORMANCE ON iTH DIMENSION

u_i = UTILITY FUNCTION, REPRESENTING CHANGING MARGINAL UTILITY, ATTITUDE TOWARD RISK

k_i = IMPORTANCE WEIGHT, REPRESENTING RELATIVE VALUE TRADEOFFS

FLOWCHART OF THE COMPLETE MUA ANALYSIS



DEFINITIONS OF SCIENTIFIC CONFIDENCE

- DEGREE TO WHICH CCDF APT TO REMAIN UNCHANGED IN RESPONSE TO FUTURE DATA, OTHER THAN EXPECTED RESOLUTION OF UNCERTAINTY
- DEMONSTRATED ABILITY TO PREDICT BEHAVIOR OF THE SYSTEM
- UNDERSTANDING: ABILITY TO INTERPRET DATA WITHIN A CONSISTENT CONCEPTUAL FRAMEWORK
- UNDERSTANDING: ABILITY TO ANSWER QUESTIONS THAT MAY BE RAISED IN LICENSING
- INVOLVEMENT OF RECOGNIZED EXPERTISE
- REASONABLE ASSURANCE

OUR OPERATIONAL DEFINITION OF SCIENTIFIC CONFIDENCE:

- SCIENTIFIC CONFIDENCE IS INCREASED BY DATA COLLECTION
- NOT JUST ANY DATA, BUT DATA THAT ADDRESSES ANY OF FIFTEEN SPECIFIC ISSUES

MUA TECHNICAL INPUTS: ISSUES

MC-1	STATISTICAL CHARACTERIZATION
MC-2	FLEXIBILITY
MC-3	ACCESS FOR IN SITU TRANSPORT TESTING
MC-4	BOUNDARIES OF CHn BARRIER
ACM-1	DETECT/CHARACTERIZE NONSYSTEMATIC SPATIAL VARIABILITY
ACM-2	FRACTURE/MATRIX SYSTEM RESPONSE
ACM-3	DETECT/CHARACTERIZE RESPONSE OF FAULTS AND FRACTURES DIRECTLY INFLUENCED BY THEM
ACM-4	DETECT/CHARACTERIZE FEATURES THAT COULD CAUSE LATERAL DIVERSION
ACM-5	DETECT/CHARACTERIZE FEATURES OR PROCESSES THAT COULD LIMIT RETARDATION
ACM-6	QUATERNARY WATER TABLE INSTABILITY
ACM-7	IMPERMANENT ROCK CHARACTERISTICS FROM NATURAL CAUSES
ACM-8	POTENTIAL CHANGES IN ROCK CHARACTERISTICS FROM CHARACTERIZATION OR REPOSITORY
SPC-1	ACCESS TO FEATURES FOR LONG-TERM TESTING
SPC-2	BASELINE DATA WHERE CHANGES ARE LIKELY
SPC-3	ACCESS TO FEATURES WHERE TESTING MAY BE REQUIRED BY OTHER PARTIES

MUA TECHNICAL INPUTS

FEATURE DEFINITION

"FEATURE" = OPPORTUNITY TO LEARN SOMETHING ABOUT THE SITE AT A PHYSICAL LOCATION

- BOUNDING/STRUCTURAL FEATURES
- FACIES
- UNKNOWN FEATURES
- PERMEABILITY CONTRASTS
- HYDROCHEMISTRY
- ACCESS OUTSIDE THE REPOSITORY BLOCK

MUA TECHNICAL INPUTS
FEATURES

A. GHOST DANCE FAULT

B. DRILL HOLE WASH

C. SOLITARIO CANYON FAULT

D. ABANDONED WASH FAULT

E. IMBRICATE NORMAL FAULT ZONE (EAST)

F. UNKNOWN FEATURES (INCL. PERCHED WATER, DIKES, ETC.)

G. VITRIC FACIES

H. ZEOLITIC FACIES

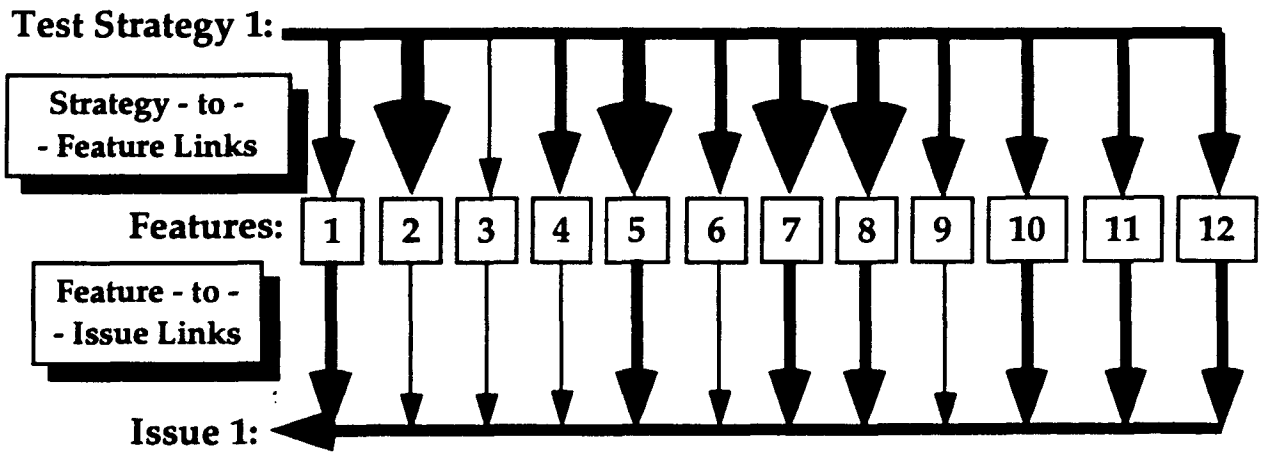
I. CHn FACIES TRANSITION

J. PERMEABILITY CONTRASTS/CAPILLARY BARRIERS

K. SITE HYDROCHEMISTRY

L. SIMILAR CONDITIONS OUTSIDE THE BLOCK

RELATIONSHIP BETWEEN TEST STRATEGIES, FEATURES, AND ISSUES



MAPPING FROM STRATEGIES TO SITE FEATURES

SITE FEATURES EXPLORED/ CHARACTERISTICS INVESTIGATED	ALTERNATIVE STRATEGIES							
	1	2	3	4	5	6	7	8
A. GHOST DANCE FAULT	✔✔	✔✔✔	✔✔		✔✔✔	✔	✔	✔
B. DRILL HOLE WASH	✔✔	✔✔	✔✔		✔✔	✔	✔	✔
C. SOLITARIO CANYON WASH	✔	✔✔		✔✔	✔✔	✔	✔	✔
D. ABANDONED WASH FAULT	✔✔✔			✔✔			✔✔✔	✔✔✔
E. IMBRICATE NORMAL FAULT ZONE (EAST)	✔✔✔	✔✔	✔✔		✔✔		✔✔	
F. UNKNOWN FEATURES INCL. PW, DIKES, etc.	✔✔	✔✔✔	✔	✔	✔✔✔		✔✔	✔
G. VITRIC FACIES	✔✔	✔✔✔		✔✔	✔✔✔	✔	✔✔	✔✔
H. ZEOLITIC FACIES	✔✔✔	✔✔✔	✔✔		✔✔✔	✔	✔	✔
I. CHn FACIES TRANSITION	✔✔	✔✔✔			✔✔✔	✔	✔✔	
J. PERMEABILITY CONTRASTS/ CAPILLARY BARRIERS	✔	✔✔✔	✔	✔	✔✔✔	✔	✔	✔
K. SITE HYDROCHEMISTRY	✔✔	✔✔✔	✔✔	✔	✔✔✔	✔	✔✔	✔✔
L. SIMILAR ROCK CONDITIONS OUTSIDE THE BLOCK	✔✔✔					✔	✔✔✔	✔✔✔

NOMENCLATURE

✔✔✔ = STRATEGY INCORPORATES AN APPROACH THAT IS THE MAXIMUM REASONABLE (e.g., EXTENSIVE DRIFTING, AS DEFINED, FOR STUDY OF FACIES)

✔✔ = FEATURE IS DIRECTLY INVESTIGATED BUT TO LIMITED EXTENT IN THE BLOCK (e.g., LIMITED EXCAVATION OF GHOST DANCE FAULT, ONLY IN THE NORTH)

✔ = FEATURE IS INVESTIGATED BY ANALOGY OR LIMITED TECHNIQUE (e.g., BOREHOLE INVESTIGATION OF FAULTS)

= STRATEGY OFFERS NO BENEFIT OVER BASELINE SCP PROGRAM (e.g., LIMITED OUTSIDE EXCAVATION TO THE NORTH, FOR STUDY OF ABANDONED WASH FAULT)

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MAPPING FROM SITE FEATURES TO ISSUES

		SITE CHARACTERISTICS FROM TABLE 1											
		A	B	C	D	E	F	G	H	I	J	K	L
ISSUE FROM NARRATIVE FOR MAXIMIZING CHARACTER-IZATION (SECTION 1.1.1)	MC-1	✔✔	✔	✔	✔	✔	✔✔	✔✔	✔✔	✔✔	✔✔	✔✔	✔
	MC-2	✔✔	✔✔	✔✔	✔✔	✔✔	✔✔	✔✔	✔✔	✔✔	✔✔	✔✔	✔
	MC-3	✔✔	✔	✔	✔	✔	✔✔	✔✔	✔✔	✔✔	✔✔	✔✔	✔✔
	MC-4	✔✔	✔✔	✔✔	✔✔	✔✔	✔	✔	✔	✔	✔✔	✔	✔
	MC-2	✔✔	✔✔	✔✔	✔✔	✔✔	✔✔	✔✔	✔✔	✔✔	✔✔	✔✔	✔
CATEGORY FROM NARRATIVE ON ALTERNATIVE CONCEPTUAL MODELS (SECTION 1.1.2)	ACM-1	✔✔	✔	✔	✔	✔	✔✔	✔✔	✔✔	✔✔	✔✔	✔✔	✔
	ACM-2	✔	✔	✔	✔	✔	✔	✔✔	✔✔	✔✔	✔✔	✔✔	✔✔
	ACM-3	✔✔	✔	✔✔	✔✔	✔✔	✔				✔	✔✔	✔
	ACM-4	✔		✔	✔	✔	✔	✔	✔	✔✔	✔✔	✔	✔
	ACM-5	✔✔	✔	✔	✔	✔	✔	✔✔	✔✔	✔✔	✔✔	✔✔	✔✔
	ACM-6	✔		✔	✔	✔	✔	✔✔	✔✔	✔✔		✔✔	✔
	ACM-7	✔	✔	✔✔	✔	✔✔	✔	✔	✔	✔	✔	✔	✔
	ACM-8	✔				✔	✔	✔	✔	✔	✔	✔	✔
ISSUE FROM NARR. FOR CAPABILITY TO SUPPORT PERF. CONFIRMATION	SPC-1	✔✔	✔	✔	✔	✔✔	✔	✔✔	✔✔	✔✔	✔✔	✔	✔✔
	SPC-2	✔	✔			✔	✔	✔	✔	✔	✔	✔	
	SPC-3	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔

NOMENCLATURE

THE INFLUENCE OF THIS FEATURE/CHARACTERISTIC ON THE PARTICULAR ASPECT OF CONFIDENCE IS:

✔✔ = STRONG, INVESTIGATION OF THIS FEATURE SIGNIFICANTLY INCREASES CONFIDENCE IN THE ISSUE (e.g., ACCESS TO GHOST DANCE FAULT IS IMPORTANT FOR IN SITU TRANSPORT TESTING

✔ = INTERMEDIATE, INVESTIGATING THIS FEATURE PROVIDES SOME INCREASE OF CONFIDENCE IN THE ISSUE (e.g. ACCESS TO THE ABANDONED WASH FAULT MAY PROVIDE ONLY LIMITED BENEFIT TO TRANSPORT TESTING)

= WEAK, THIS FEATURE HAS NEGLIGIBLE INFLUENCE ON CONFIDENCE IN THE ISSUE

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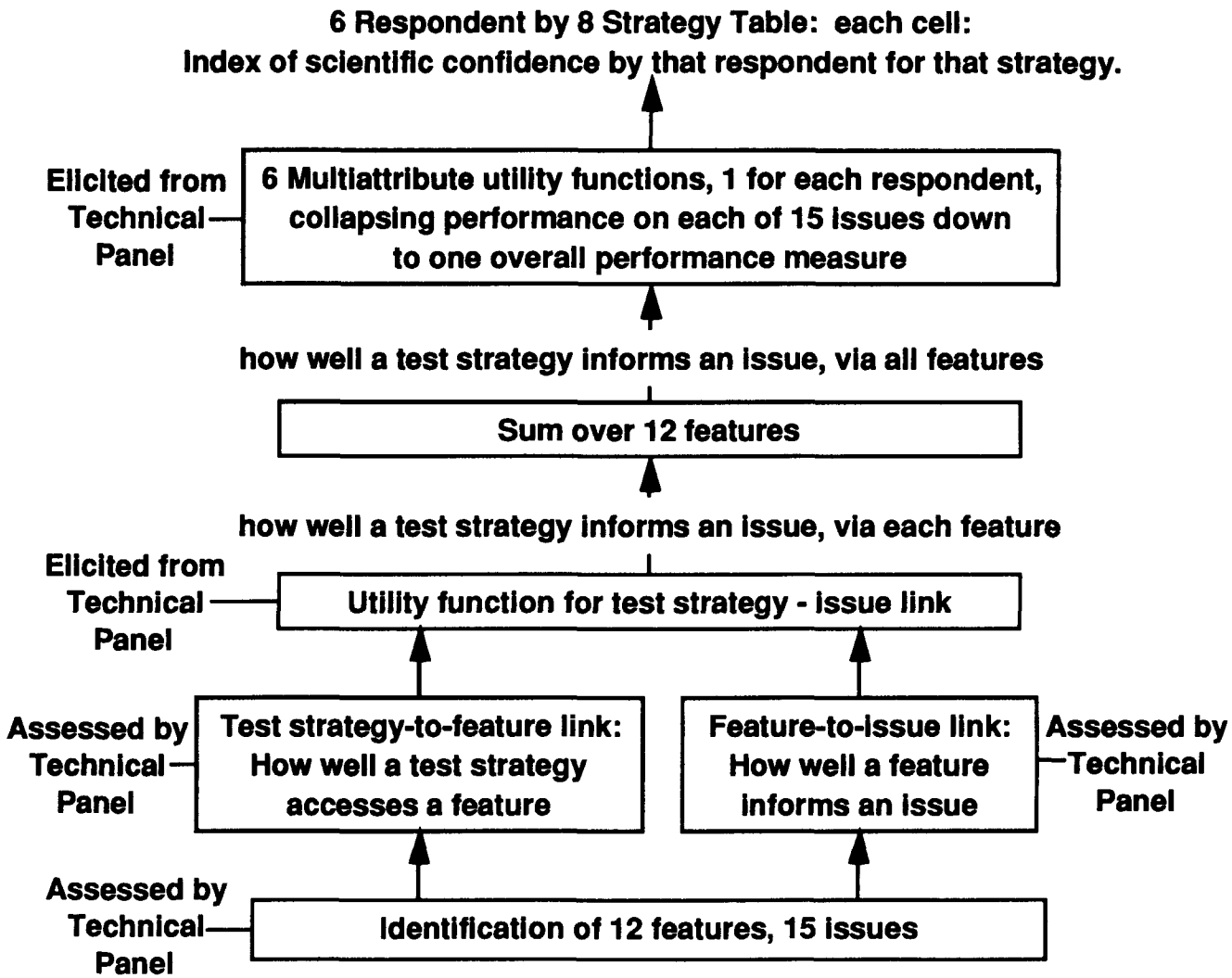
Flowchart of Scientific Confidence MUA



UTILITY FUNCTION FOR TEST-ISSUE LINK

Feature-Issue Link:	Test-Feature Link: 0	1	2	3
0	0	0	0	0
1	0	0.5	0.7	0.8
2	0	0.7	0.8	1

TEST STRATEGY 1
U (SCIENTIFIC CONFIDENCE)

Feature: / Issue	1 A	2 B	3 C	4 D	5 E	6 F	7 G	8 H	9 I	10 J	11 K	12 L	Sum
MC-1	.8	.7	.5	.8	.8	.8	.8	1.0	.8	.7	.8	.8	9.3
MC-2	.8	.8	.7	1.0	1.0	.8	.8	1.0	.8	.7	.8	.8	10.0
MC-3	.8	.7	.5	.8	.8	.8	.8	1.0	.8	.7	.8	1.0	9.5
MC-4	.8	.8	.7	1.0	1.0	.7	.7	.8	.7	.7	.7	.8	9.4
ACM-1	.8	.7	.5	.8	.8	.8	.8	1.0	.8	.7	.8	.8	9.3
ACM-2	.7	.7	.5	.8	.8	.7	.8	1.0	.8	.7	.8	1.0	9.3
ACM-3	.8	.7	.7	1.0	1.0	.7	.0	.0	.0	.5	.8	.8	7.0
ACM-4	.7	.0	.5	.8	.8	.7	.7	.8	.8	.7	.7	.8	8.0
ACM-5	.8	.7	.5	.8	.8	.7	.8	1.0	.8	.7	.8	1.0	9.4
ACM-6	.7	.0	.5	.8	.8	.7	.8	1.0	.8	.0	.8	.8	7.7
ACM-7	.7	.7	.7	.8	1.0	.7	.7	.8	.7	.5	.7	.8	8.8
ACM-8	.7	.0	.0	.0	.8	.7	.7	.8	.7	.5	.7	.8	6.4
SPC-1	.8	.7	.5	.8	1.0	.7	.8	1.0	.8	.7	.7	1.0	9.5
SPC-2	.7	.7	.0	.0	.8	.7	.7	.8	.7	.5	.7	.0	6.3
SPC-3	.7	.7	.5	.8	.8	.7	.7	.8	.7	.5	.7	.8	8.4

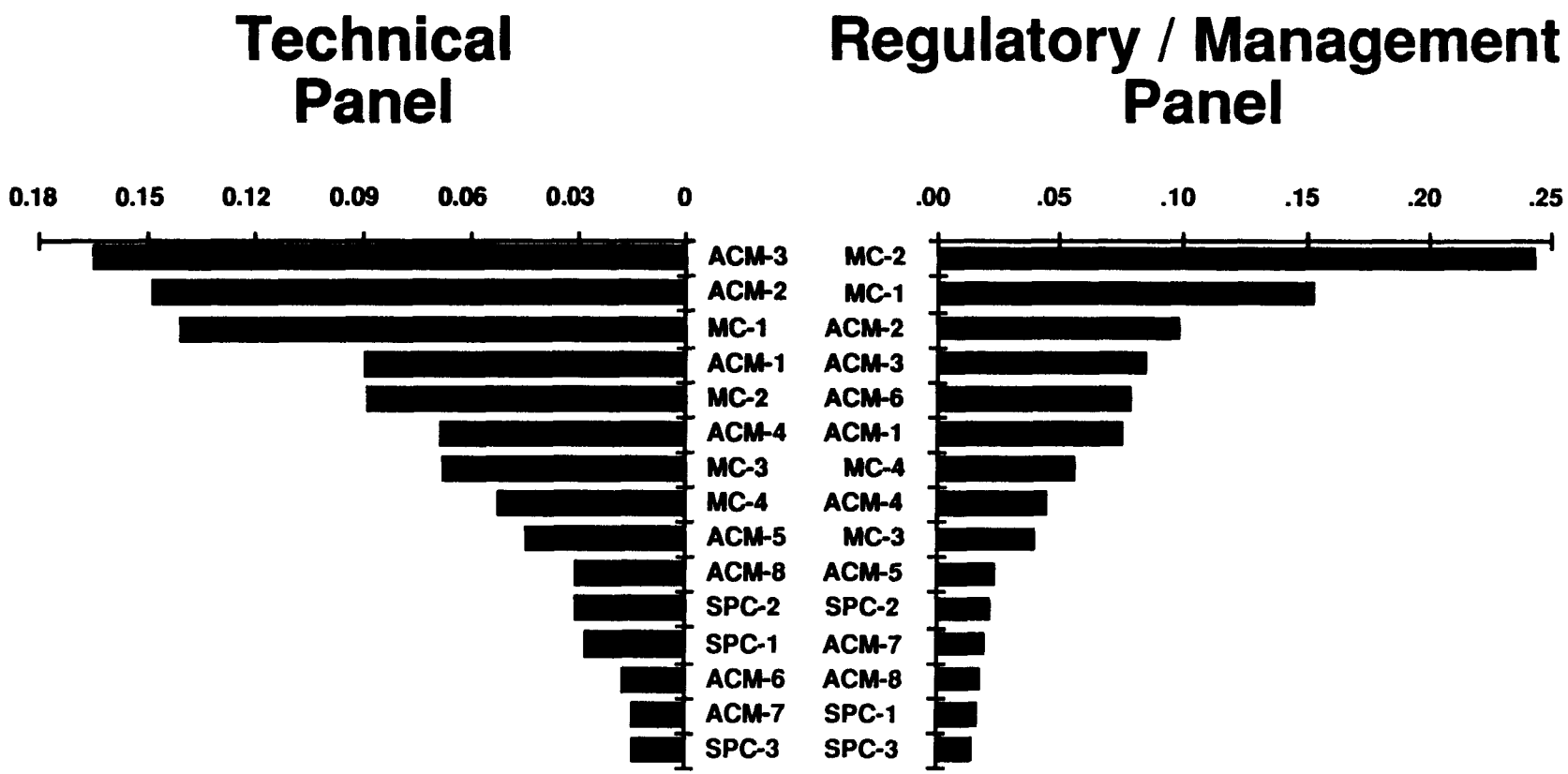
TEST STRATEGY 2
U (SCIENTIFIC CONFIDENCE)

Feature: / Issue	1 A	2 B	3 C	4 D	5 E	6 F	7 G	8 H	9 I	10 J	11 K	12 L	Sum
MC-1	1.0	.7	.7	.0	.7	1.0	1.0	1.0	1.0	1.0	1.0	.0	9.1
MC-2	1.0	.8	.8	.0	.8	1.0	1.0	1.0	1.0	1.0	1.0	.0	9.4
MC-3	1.0	.7	.7	.0	.7	1.0	1.0	1.0	1.0	1.0	1.0	.0	9.1
MC-4	1.0	.8	.8	.0	.8	.8	.8	.8	.8	1.0	.8	.0	8.4
ACM-1	1.0	.7	.7	.0	.7	1.0	1.0	1.0	1.0	1.0	1.0	.0	9.1
ACM-2	.8	.7	.7	.0	.7	.8	1.0	1.0	1.0	1.0	1.0	.0	8.7
ACM-3	1.0	.7	.8	.0	.8	.8	.0	.0	.0	.8	1.0	.0	5.9
ACM-4	.8	.0	.7	.0	.7	.8	.8	.8	1.0	1.0	.8	.0	7.4
ACM-5	1.0	.7	.7	.0	.7	.8	1.0	1.0	1.0	1.0	1.0	.0	8.9
ACM-6	.8	.0	.7	.0	.7	.8	1.0	1.0	1.0	.0	1.0	.0	7.0
ACM-7	.8	.7	.8	.0	.8	.8	.8	.8	.8	.8	.8	.0	7.9
ACM-8	.8	.0	.0	.0	.7	.8	.8	.8	.8	.8	.8	.0	6.3
SPC-1	1.0	.7	.7	.0	.8	.8	1.0	1.0	1.0	1.0	.8	.0	8.8
SPC-2	.8	.7	.0	.0	.7	.8	.8	.8	.8	.8	.8	.0	7.0
SPC-3	.8	.7	.7	.0	.7	.8	.8	.8	.8	.8	.8	.0	7.7

ISSUE WEIGHTS FOR SCIENTIFIC CONFIDENCE

Technical Panel			Regulatory / Management Panel		
Short Name	Av'g Wt.	Issue	Issue	Av'g Wt.	Short Name
Fault System	.16	ACM-3	MC-2	.24	Flexibility
Fracture / Matrix System	.15	ACM-2	MC-1	.15	Statistical Characterization
Statistical Characterization	.14	MC-1	ACM-2	.10	Fracture / Matrix System
Spatial Variability	.09	ACM-1	ACM-3	.09	Fault System
Flexibility	.09	MC-2	ACM-6	.08	Water Table Instability
Lateral Flow	.07	ACM-4	ACM-1	.08	Spatial Variability
In Situ Active Testing	.07	MC-3	MC-4	.06	Boundary Conditions
Boundary Conditions	.05	MC-4	ACM-4	.05	Lateral Flow
Retardation	.04	ACM-5	MC-3	.04	In Situ Active Testing
Man-Caused Rock Changes	.03	ACM-8	ACM-5	.02	Retardation
Passive Mon'g: Man-Caused Eff's	.03	SPC-2	SPC-2	.02	Passive Mon'g: Man-Caused Eff's
Long-Term Active Monitoring	.03	SPC-1	ACM-7	.02	Natural-Cause Rock Changes
Water Table Instability	.02	ACM-6	ACM-8	.02	Man-Caused Rock Changes
Natural-Cause Rock Changes	.01	ACM-7	SPC-1	.02	Long-Term Active Monitoring
Accomodate Other's Requests	.01	SPC-3	SPC-3	.02	Accomodate Other's Requests

ISSUE WEIGHTS FOR SCIENTIFIC CONFIDENCE



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UTILITY TRANSFORM OF TABLE 2.6.2.2.1-7
UTILITY OF RESPONDENT A

ISSUE	TEST STRATEGY: 1	2	3	4	5	6	7	8	A WT.
MC-1	1.06	1.02	.24	.06	1.02	.34	.92	.58	.05
MC-2	1.00	.89	.16	.00	.89	.29	.87	.55	.01
MC-3	1.10	1.02	.24	.06	1.02	.38	.96	.60	.15
MC-4	1.05	.93	.55	.00	.93	.58	.97	.76	.05
ACM-1	1.06	1.02	.24	.06	1.02	.34	.92	.58	.20
ACM-2	1.03	.97	.50	.06	.97	.63	.94	.73	.05
ACM-3	1.00	.73	.28	.08	.73	.15	.88	.60	.19
ACM-4	1.00	.90	.41	.33	.90	.45	.90	.62	.15
ACM-5	1.08	.98	.20	.02	.98	.38	.94	.56	.03
ACM-6	.95	.82	.15	.12	.82	.35	.84	.51	.02
ACM-7	1.05	.89	.32	.06	.89	.33	.89	.57	.01
ACM-8	.93	.92	.62	.10	.92	.57	.86	.66	.03
SPC-1	1.10	.96	.20	-.02	.96	.34	.94	.54	.03
SPC-2	.92	1.00	.71	.10	1.00	.59	.83	.64	.03
SPC-3	.98	.86	.30	.03	.86	.30	.84	.53	.01
									1.00
MAU =	1.04	.927	.317	.098	.927	.365	.913	.607	
ULE =	8.49	7.92	4.75	3.81	7.92	4.96	7.84	6.24	

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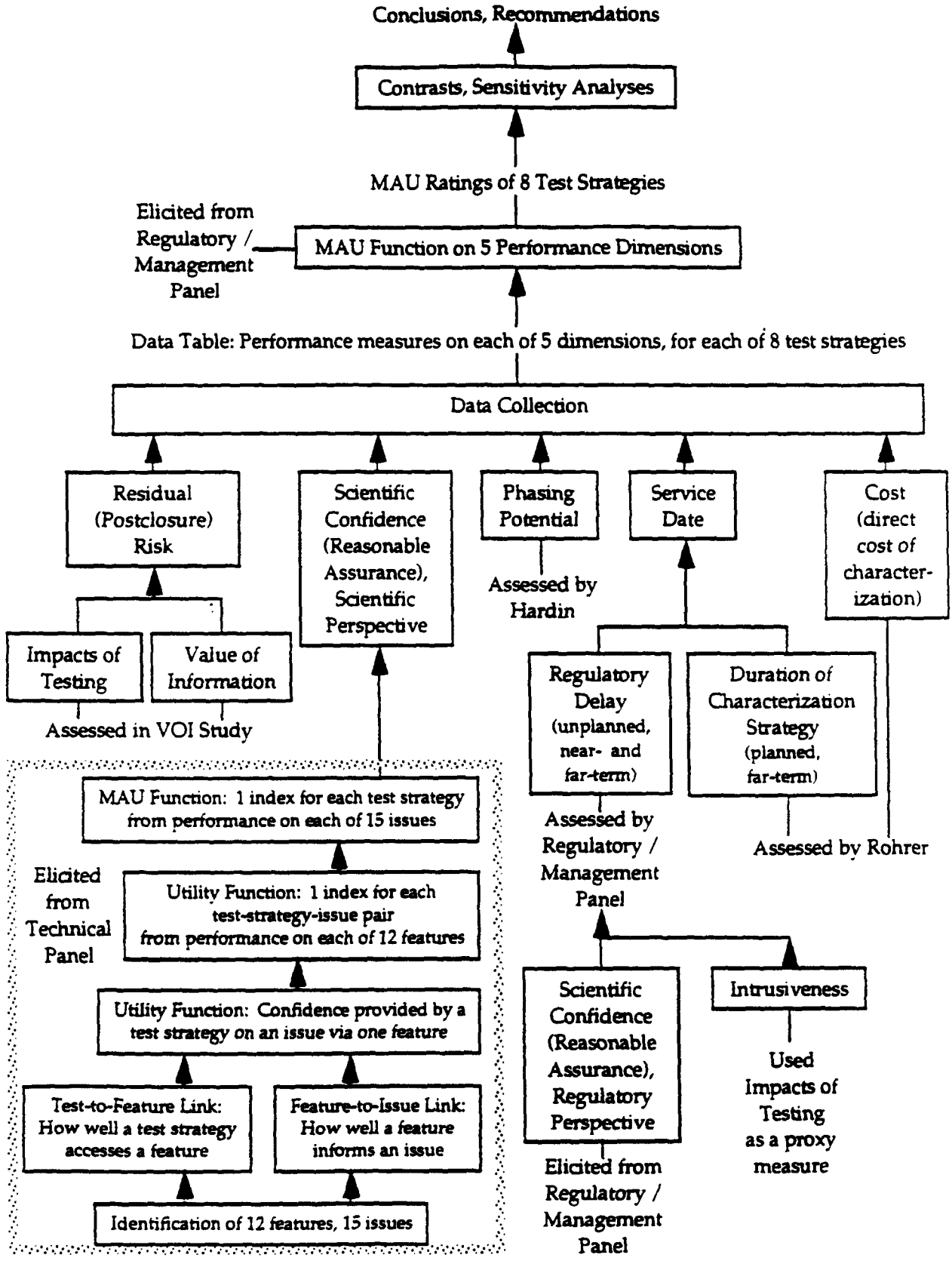
SCIENTIFIC CONFIDENCE RESULTS

Equivalent Number of Maximum-Strong Looks at Every One of the 15 Issues								Root Sum Squared Difference From:	
Strategy: Respondent	1	2,5	3	4	6	7	8	Average	D
A	8.5	7.9	4.8	3.8	5.0	7.8	6.2	.31	1.65
B	8.7	8.3	4.8	3.8	5.1	8.0	6.2	.32	2.17
C	9.2	8.7	5.0	3.9	5.5	8.5	6.7	1.32	3.24
D	7.9	7.0	4.7	3.9	4.7	7.3	5.9	1.93	.00
E	9.2	8.7	5.0	3.9	5.4	8.5	6.7	1.26	3.18
F	8.4	7.7	4.7	3.8	4.9	7.8	6.2	.59	1.38
Average:	8.6	8.0	4.8	3.9	5.1	8.0	6.3	.95	1.94

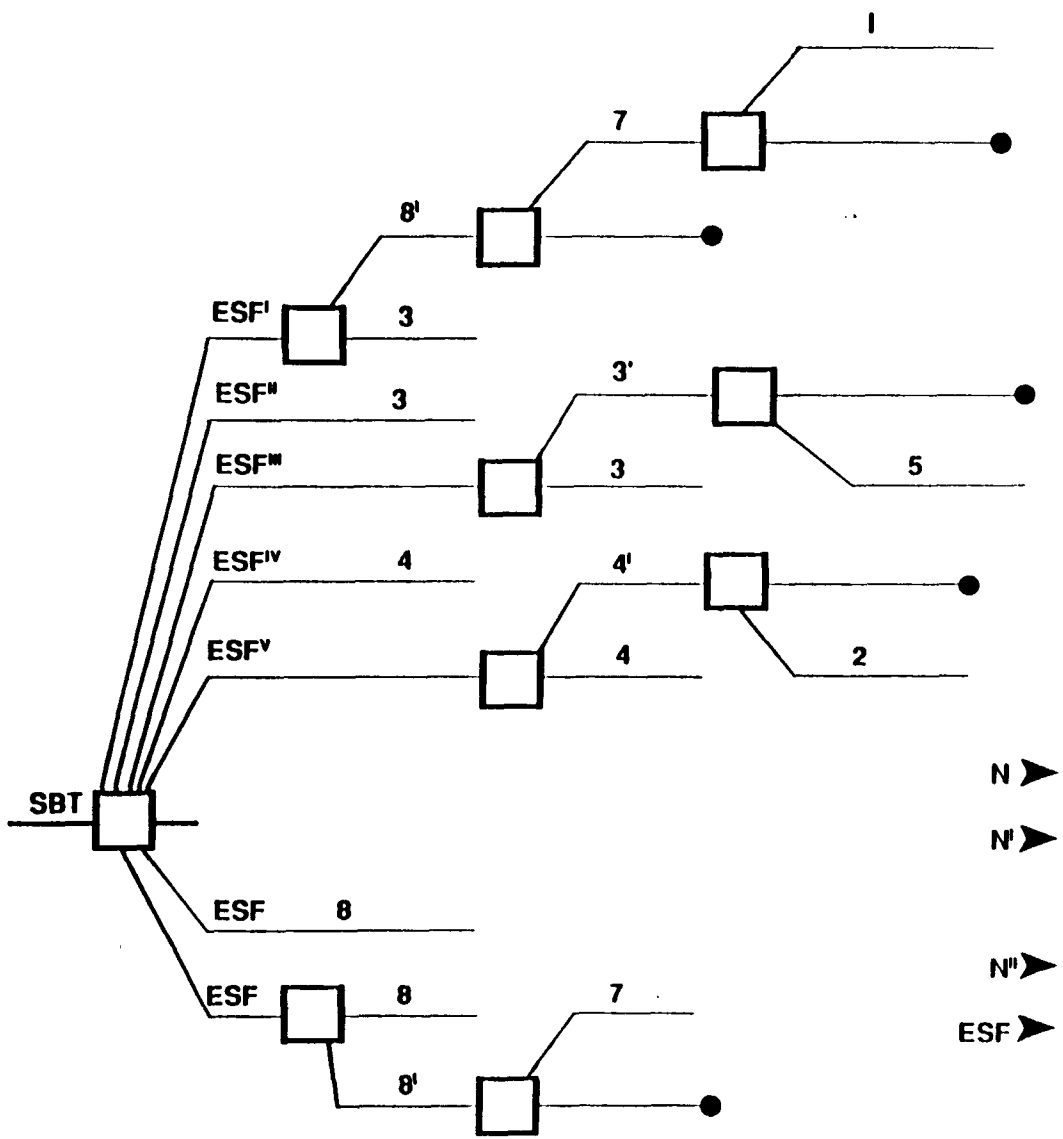
SCIENTIFIC CONFIDENCE RESULTS: RANK ORDERS

Strategy: / Respondent	1	2,5	3	4	6	7	8
A	1	2	6	7	5	3	4
B	1	2	6	7	5	3	4
C	1	2	6	7	5	3	4
D	1	3	6	7	5	2	4
E	1	2	6	7	5	3	4
F	1	3	6	7	5	2	4
Average:	1	2	6	7	5	3	4

FLOWCHART OF THE COMPLETE MUA ANALYSIS



PHASING DIAGRAM WITH INITIAL SBT



N ➤ CHSTRATEGY N

N' ➤ UNIQUE IMPLEMENTATION OF ESF OR STRATEGY N W/ CAPABILITY FOR SPECIFIC ADDITIONAL ACTIVITIES

N'' ➤ ANOTHER UNIQUE IMPLEMENTATION....

ESF ➤ EXPLORATORY SHAFT FACILITY

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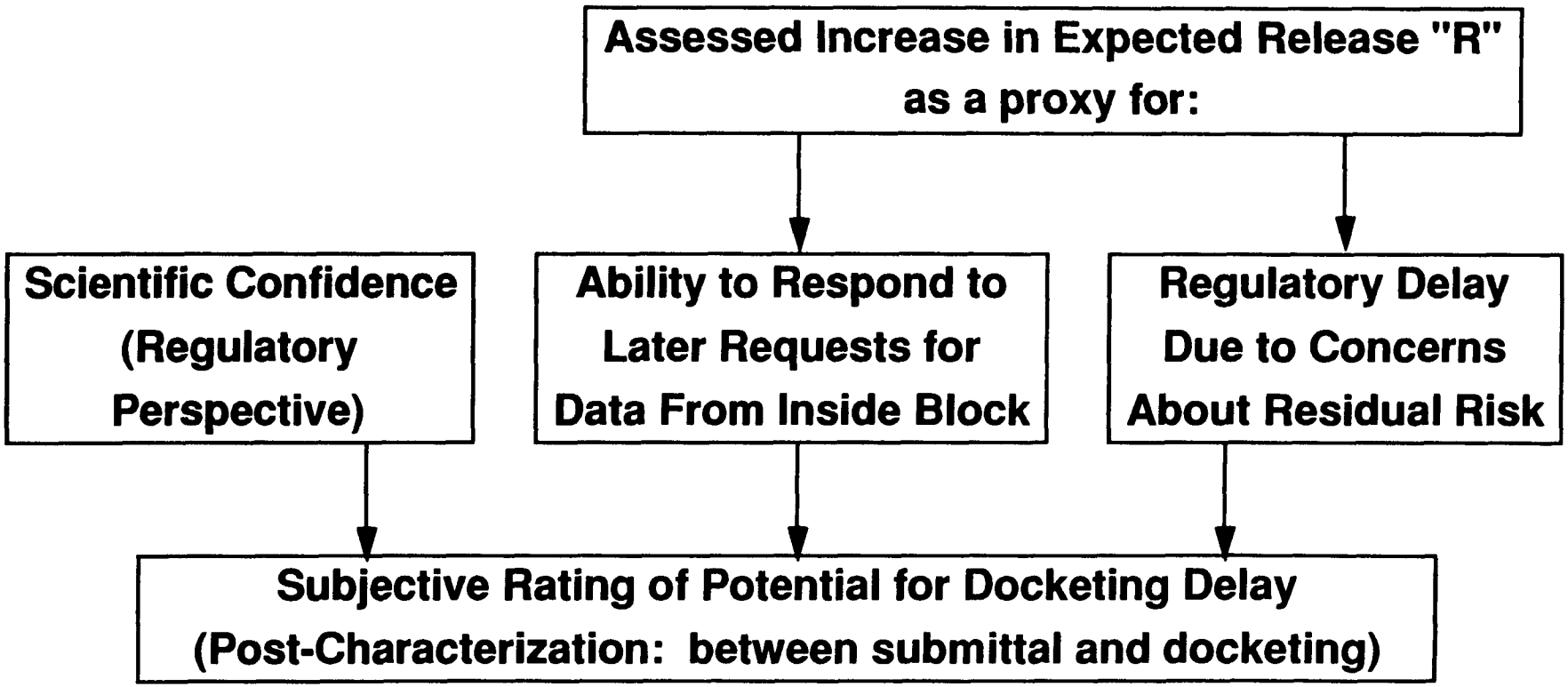
FLOWCHART FOR DELAY SCALE JUDGMENTS



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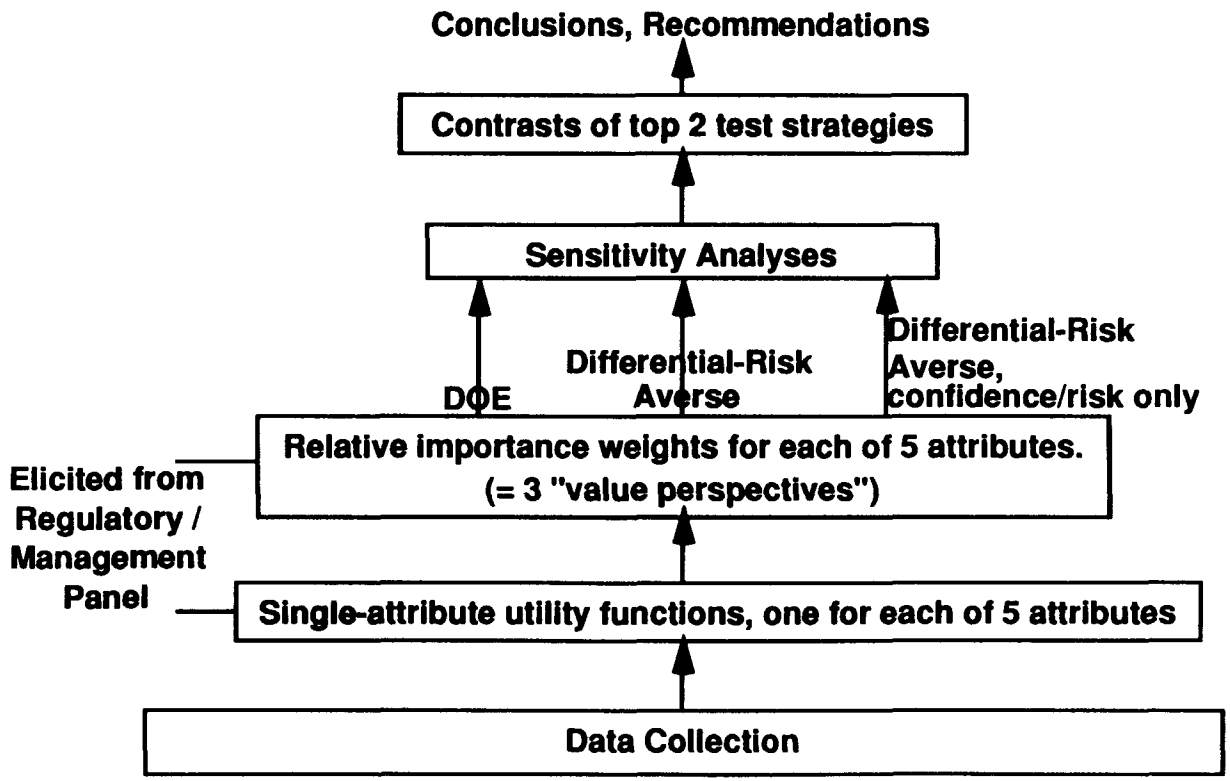
DELAY DATA, SCALE:

Delay Scale Level	Test Strategy	Scientific Confidence (Reg/Mgmt Perspect'v)	Two Minimum-Confidence Issues		Risk Concern and In-Block Flexibility (change in R as a proxy)	
5	2,5	8.4	5.9	6.3	2E-5	13%
4	1	8.9	6.3	6.4	5E-6	3%
3	3	4.8	3.5	3.8	4E-6	3%
3	7	8.2	5.5	5.8	2E-7	<1%
3	4	4.0	2.2	2.2	4E-6	2%
2	8	6.5	3.9	4.1	1E-7	<1%
1	6	5.3	3.5	3.5	3E-6	2%

FLOWCHART OF FIVE-ATTRIBUTE MUA



DIRECT PERFORMANCE DATA

STRATEGY:	1	2,5	3	4	6	7	8	UNITS
SCI CONF'C: BASE CASE	8.6	8.0	4.8	3.9	5.1	8.0	6.3	EQUIVALENT NUMBER OF "MAXIMUM-STRONG LOOKS" AT EVERY ONE OF 15 ISSUES
RESID RISK	.031	.13	.028	.023	.020	.0011	.00087	FRACTION INCREMENT
RESID RISK	.0047	.020	.0042	.0035	.0030	.0002	.0001	INCREASED EXPECTED FATALITIES
RESID RISK	15.5E-5	17.0E-5	15.4E-5	15.4E-5	15.3E-5	15.0E-5	15.0E-5	FRACTION OF EPA LIMIT
DELAY	4	5	3	3	1	3	2	LEVELS DEFINED IN TEXT
COST	174	116	52	52	0	113	78	$MM DIFFERENTIAL
PHASING	4	2	1	1	1	3	2	NUMBER OF OPTIONS

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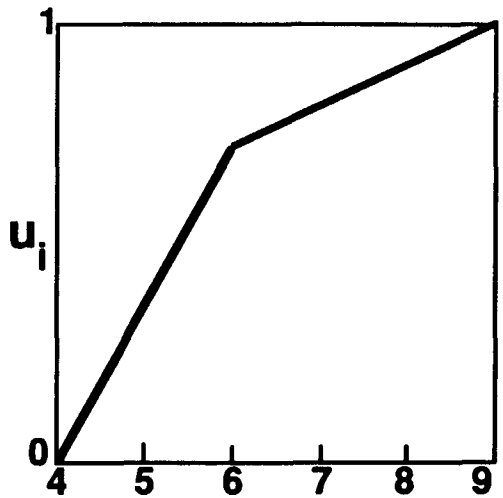
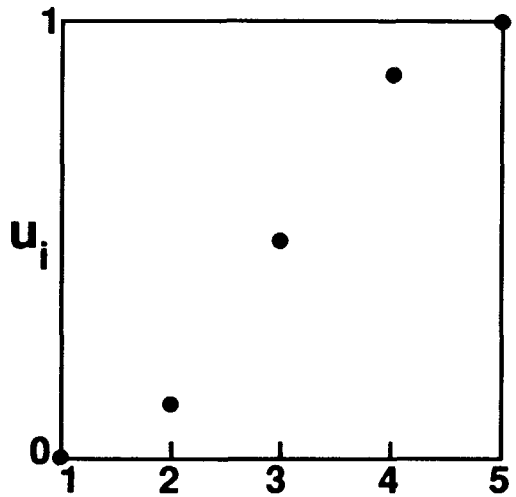
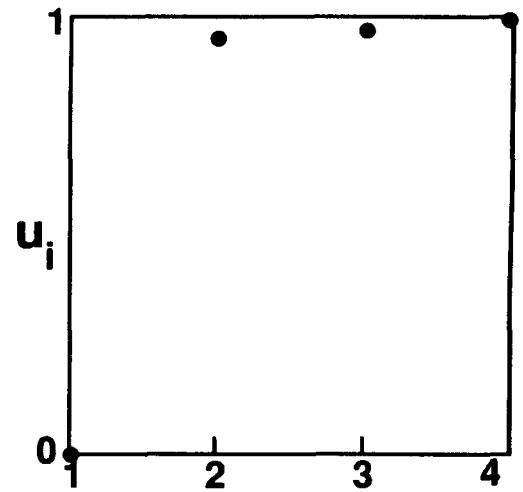
SINGLE-ATTRIBUTE UTILITY FUNCTIONS



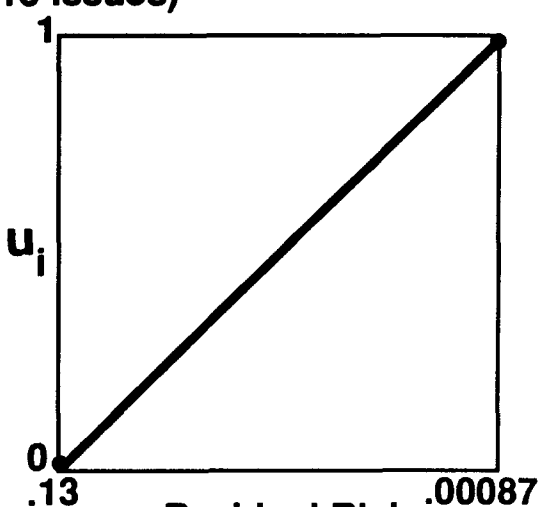
Scientific Confidence
(equiv. max-strong looks
at @ of 15 issues)



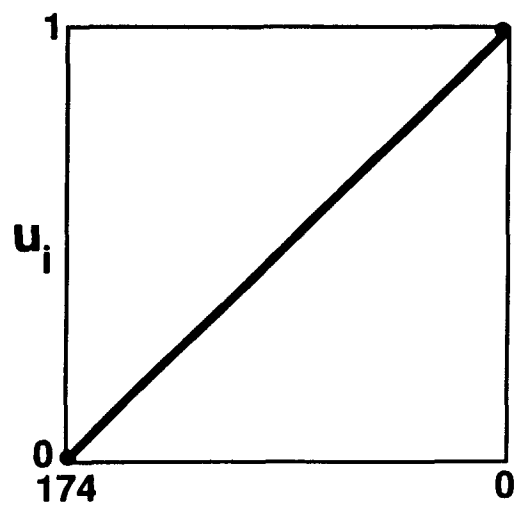
Delay (5 subjective levels)



Phasing Potential
(# ways can end)



Residual Risk
(fraction increment)



Cost ($million differential)

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WEIGHTS ON THE FIVE ATTRIBUTES, FROM THREE PERSPECTIVES

DOE Perspective

Attribute	Respondent: A	B	C	D	E	F	G	Average
Confidence	.45	.47	.42	.61	.36	.35	.44	.44
Resid Risk	.05	.06	.10	.03	.05	.06	.06	.06
Delay	.22	.23	.19	.25	.29	.23	.28	.24
Cost	.19	.15	.19	.08	.23	.29	.15	.18
Phasing	.09	.08	.10	.04	.07	.07	.07	.07

Differential-Risk Averse Perspective

Attribute	Respondent: A	B	C	D	E	F	G	Average
Confidence	.50	.41	.37	.47	.41		.33	.42
Resid Risk	.35	.39	.37	.19	.28		.42	.33
Delay	.08	.13	.18	.22	.26		.15	.17
Cost	.04	.05	.04	.07	.04		.08	.05
Phasing	.04	.02	.03	.04	.01		.02	.03

Differential-Risk Averse Perspective, Confidence and Risk Only

Attribute	Respondent: A	B	C	D	E	F	G	Average
Confidence	.57	.51	.50	.58	.58		.46	.53
Resid Risk	.43	.49	.50	.42	.42		.54	.47

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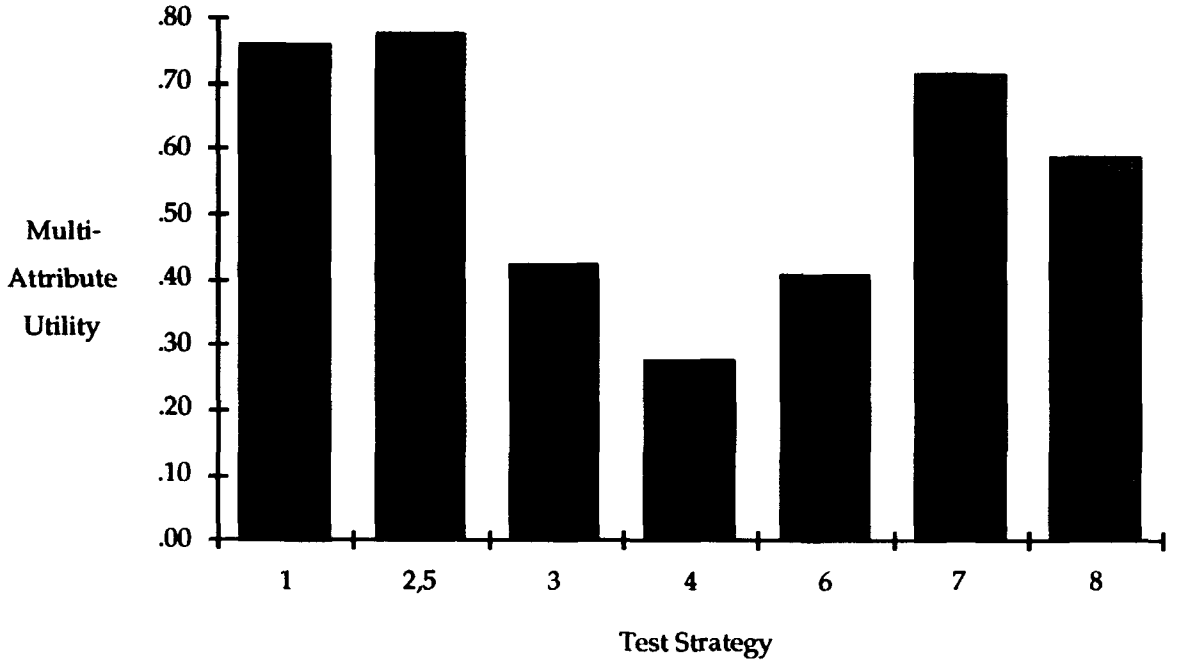
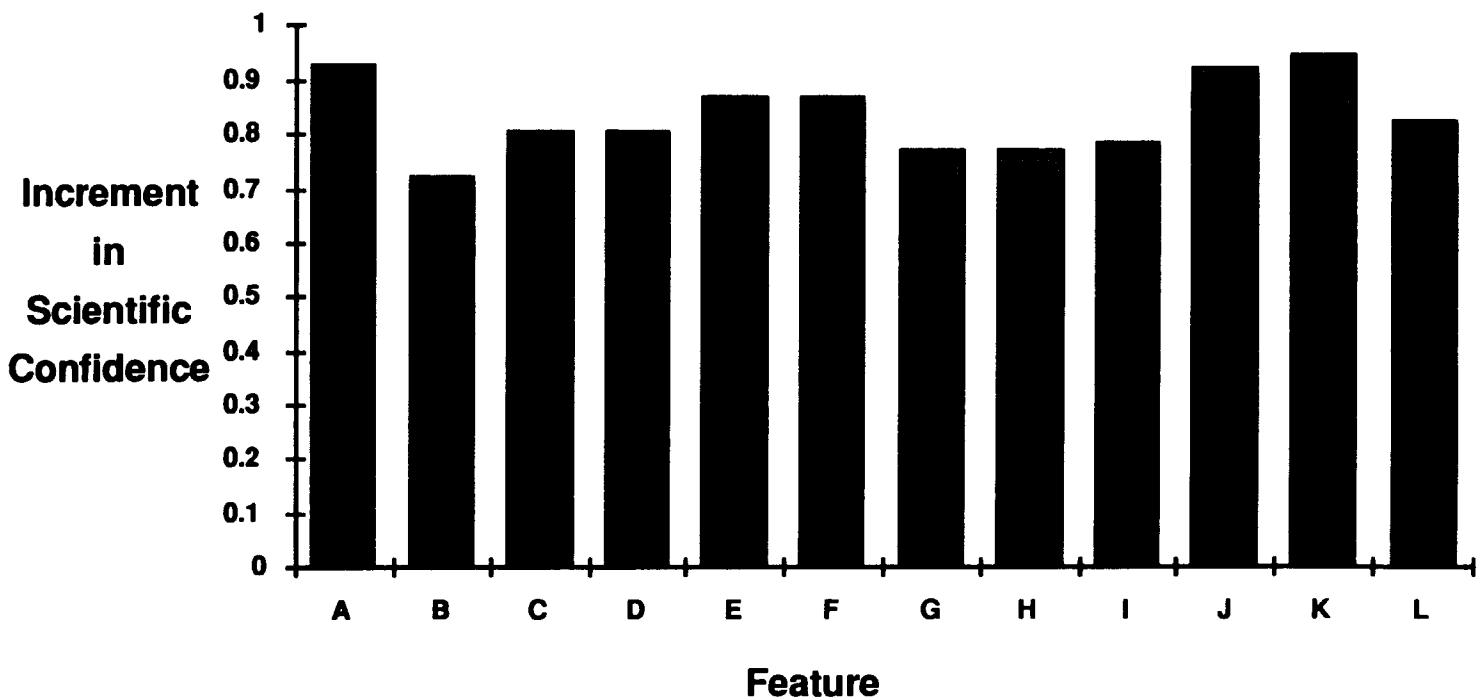
DOE PERSPECTIVE MULTIATTRIBUTE UTILITY



DOE PERSPECTIVE MAU RANK ORDERS, CONFIDENCE BASE CASE

STRATEGY:		1	2,5	3	4	6	7	8
RESP'T:	A	2	1	5	7	6	3	4
	B	2	1	5	7	6	3	4
	C	1	3	6	7	5	2	4
	D	1	2	5	7	6	3	4
	E	2	1	5	7	6	3	4
	F	3	1	6	7	5	2	4
	G	2	1	5	7	6	3	4
AVERAGE:		2	1	5	7	6	3	4

SCIENTIFIC CONFIDENCE PROVIDED BY EACH FEATURE



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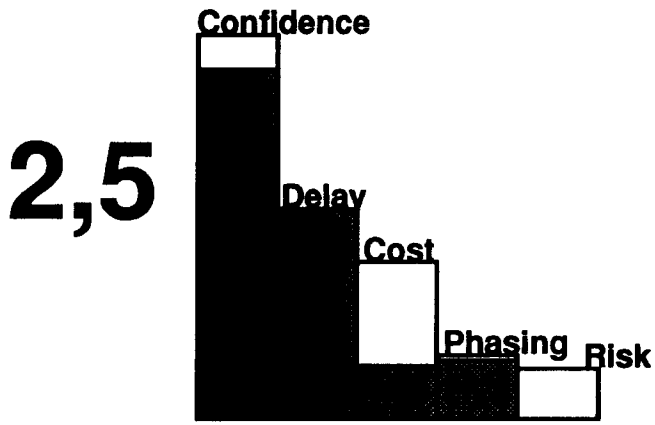
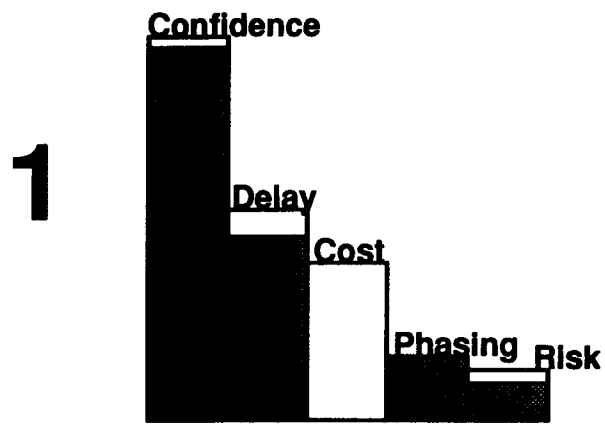
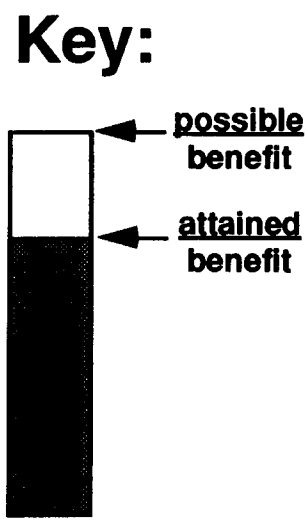
Contrasting Test Strategies 2,5 vs 1







CONTRAST TABLE: STRATEGIES 2,5 vs 1

Attribute	Data 2,5	Data 1	Utility 2,5	Utility 1	Diff'c	DOE Weight	Weight'd Differ'c
Confidence	8.0	8.6	.91	.97	-.05	.44	-.02
Delay	5	4	1.00	.88	.13	.24	.03
Cost	116	174	.33	.00	.33	.18	.06
Phasing	2	4	.95	1.00	-.05	.07	.00
Resid Risk	.13	.031	.00	.77	-.77	.06	-.05
						Sum=	.02

Contrasting Strategies 2,5 vs 1

"Going from Strategy 2,5 to 1," You come out behind:

PRO:		CON:	
- risk	(+.05)	+ cost	(-.06)
+ confidence	(+.02)	+ potential delay	(-.03)
	(+.07)		(-.09)

But that depends on relative weight given to risk

(note other value perspectives)

That is a difficult value tradeoff.

We can finesse that tradeoff

by transforming the contrast to cost per life saved.

Strategies 2,5 to 1 Transformed to Cost Per Life Saved

	1	2,5
Confidence	8.6	8.0
Delay	4	5
Cost	174	116
Phasing	4	2
Resid'l Risk	.0047	.020

=>

diff'c in MAU

=

.068

=>

1'	2',5'
8.3	8.3
5	5
177	116
4	4

=> 4-Attribute Difference is Equivalent to $61 million

That is,

Moving from Strategy 2,5 to 1 is equivalent to:

spending $61 million to reduce expected fatalities by .015,

Which amounts to over $4 billion per life saved.

Discussion: General Findings

- Strategy 2,5 is the most desirable of the 8 strategies considered, but it is not much more desirable than Strategy 1.

- More generally:
  extensive excavation in the Calico Hills unit repository block provides a net benefit,
  compared to minimum excavation there, considering
  risk, scientific confidence, delay, cost and phasing potential.

- The robustness of the ranking of Strategy 2,5 over Strategy 1 could be increased by:
  - adding feature accesses to Strategy 2,5;
  - a more refined elicitation of importance weights.

Discussion: Qualifications to Findings

1. "Differential-risk-averse perspective"

   ranks Strategy 2,5 below Strategies 7, 1 and 8.

2. Adding feature accesses to Strategy 2,5

   increases the robustness with which it is ranked over Strategy 1,

   though it does not change

   the differential-risk-averse perspective ranking.

3. The ranking results are robust with respect to

   uncertainty in scientific confidence.

Discussion: More General Insights

1. Access to each of the features
   provides a similar increment in scientific confidence,
   so in general, the more features accessed, the better.

2. The relative weight given to residual risk as elicited here
   (i.e., with a strong component of differential-risk-aversion)
   is critical to the ranking of alternative strategies,
   though a more refined elicitation
   would probably reduce that sensitivity.

3. Delay and cost considerations can be just as significant
   as residual risk and scientific confidence
   in the ranking of strategies,
   so it is important to consider at least those four attributes.